Evolution of Elasticity of Demand for Coal in China and the United States[1]

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[1] https://github.com/gelkouh/econ-21110-winter-2023

Where we are

Motivation

- Coal is the largest source of electricity generation globally (just over a third of total electricity generation according to the International Energy Agency)
- ... but coal is also the largest single source of carbon dioxide emissions!
- Knowing the elasticity of demand for coal helps inform creation of policies that provide incentives for substitute energy sources, etc.

Research questions

- Research questions: What is the price elasticity of demand for coal? How has price elasticity of demand for coal changed over time?
- Replication
  - Burke and Liao (2015), "Is the price elasticity of demand for coal in China increasing?"
  - As of 2012, estimates via OLS with selection on observables strategy that price elasticity of demand for coal was in the range -0.3 to -0.7
  - Finds that price elasticity of demand for coal in Chine became more elastic from 1998 to 2012
- Extension
  - Understand external validity of Burke and Liao (2015) results by estimating elasticity of demand for coal in the United States
  - Use "better" (i.e., more granular) data: coal mine-power plant contracts instead of aggregated data
  - Employ an IV strategy alongside the selection on observables approach from the replication

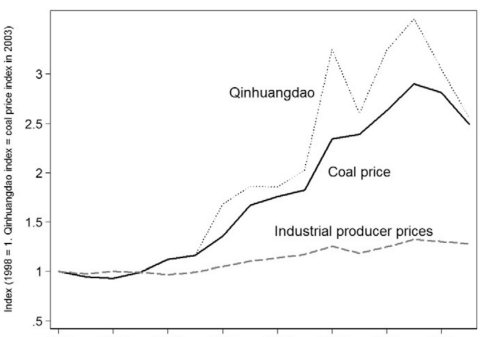
Where we are

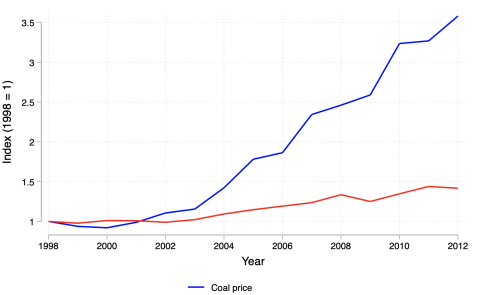
Data

- Yearly provincial panel data for 1998–2012 covering 30 provincial-level divisions in Mainland China: 22 (formal) provinces, 4 municipalities (Beijing, Tianjin, Shanghai, and Chongqing), and 4 autonomous regions (Inner Mongolia, Guangxi, Ningxia, and Xinjiang)
- There are some missing observations in the replication file provided by authors (see figures on next slide)

	mean	sd	min	max
Ln Coal consumption	4.106663	.9305527	.5247285	5.997397
Ln Real coal price index	4.098127	.4318536	2.793868	4.774778
Time trend	7	4.325147	0	14
Ln GDP	8.222613	1.110345	4.524124	10.45717
Observations	465			

Figure


Index (1998 = 1, Qinhuangdao index = coal price index in 2003)
.5
1
1.5
2
2.5
3
1998
2000
2002
2004
2006
2008
2010
2012
Qinhuangdao
Coal price
Industrial producer prices


Index (1998 = 1)
1
1.5
2
2.5
3
3.5
1998
2000
2002
2004
2006
2008
2010
2012
Year
Coal price
Industrial producer prices

Empirical strategy

Main OLS regression specifications:

$$\log(C_{pt}) = \beta_1 \log(P_{pt}) + \beta_2 \ln(Y_{pt}) + \beta_3 t + \delta_p + \epsilon_{pt}$$
$$\log(C_{pt}) = \beta_1 \log(P_{pt}) + \beta_2 \log(Y_{pt}) + \beta_3 t + \beta_4 (t \times \log(P_{pt})) + \delta_p + \epsilon_{pt}$$
$$\log(C_{pt}) = \beta_1 \log(P_{pt}) + \beta_2 \log(Y_{pt}) + \beta_3 t + \beta_4 (t \times \log(P_{pt})) + \beta_5 \log(P_{pt-2}) + \beta_6 \log(t \times P_{pt-2}) + \delta_p + \epsilon_{pt}$$

- time period $t \in \{0, ..., T\}$, province p
- C_{pt}: primary coal consumption
- P_{pt}: output price index
- Y_{pt}: real GDP
- δ_p: province fixed effect

Empirical results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ln Real coal price index_p,t	-0.0254	0.0795	-0.179**	0.0692	0.159*	0.162	0.0523	-0.183***	0.0740
	(0.1382)	(0.1303)	(0.0718)	(0.1407)	(0.0809)	(0.0993)	(0.0952)	(0.0657)	(0.1361)
Ln GDP_p,t	1.186***	1.420***	1.291***	1.269***	1.111***	1.112***	1.256***	1.234***	1.088***
	(0.2697)	(0.2967)	(0.3550)	(0.2548)	(0.2969)	(0.2896)	(0.4221)	(0.3050)	(0.2711)
Time trend_t	-0.0365	-0.0555**	-0.0605	0.0869*	-0.0224	-0.0225	-0.0212	-0.0323	0.215***
	(0.0230)	(0.0246)	(0.0388)	(0.0471)	(0.0267)	(0.0264)	(0.0396)	(0.0304)	(0.0684)
Ln Real coal price index_p,t × Time trend_t				-0.0301**					-0.0284*
				(0.0114)					(0.0147)
Ln Real coal price index_p,t-1					0.00883				
					(0.0740)				
Ln Real coal price index_p,t-2					-0.263***	-0.259***	-0.0722	-0.237***	0.0267
					(0.0624)	(0.0840)	(0.1247)	(0.0817)	(0.1831)
Ln Real coal price index_p,t-2 × Time trend_t									-0.0243
									(0.0171)
Constant	-5.211***	-7.492***	-5.194*	-6.252***	-4.381**	-4.388**	-5.892**	-3.926*	-5.069***
	(1.6401)	(1.9029)	(2.6460)	(1.6893)	(1.8495)	(1.8143)	(2.7218)	(2.2306)	(1.8172)
Province fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	379	255	124	379	320	320	196	124	320
R^2	0.975	0.981	0.994	0.977	0.979	0.979	0.985	0.994	0.982
Adjusted R^2	0.972	0.978	0.992	0.974	0.976	0.976	0.981	0.992	0.980

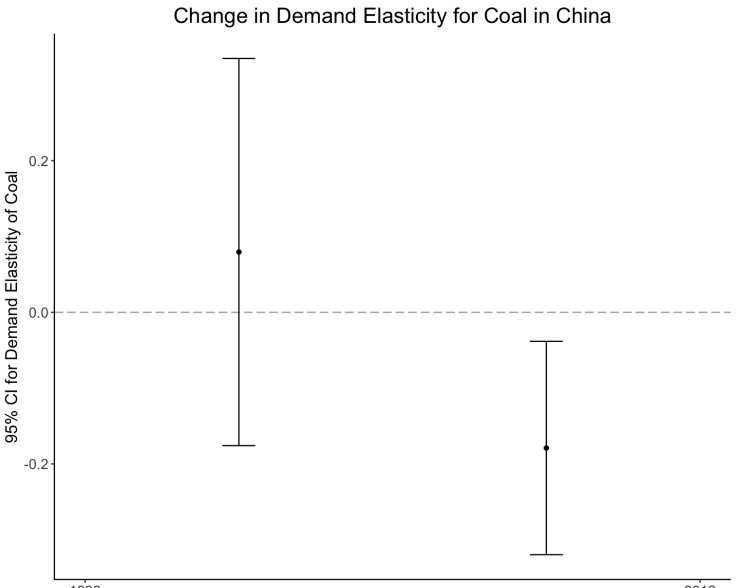
Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Columns 1, 4, 5, 6, and 9 use the full sample; columns 2 and 7 use 1998-2007 ("early"); columns 3 and 8 use 2008-2012 ("late"). Standard errors clustered at Province level.

$\Rightarrow$ Price elasticity point estimates are: (1) -0.0254 (mean); (2) 0.0795 (mean); (3) -0.179 (mean); (4) -0.3522 (in 2012); etc.

Empirical results



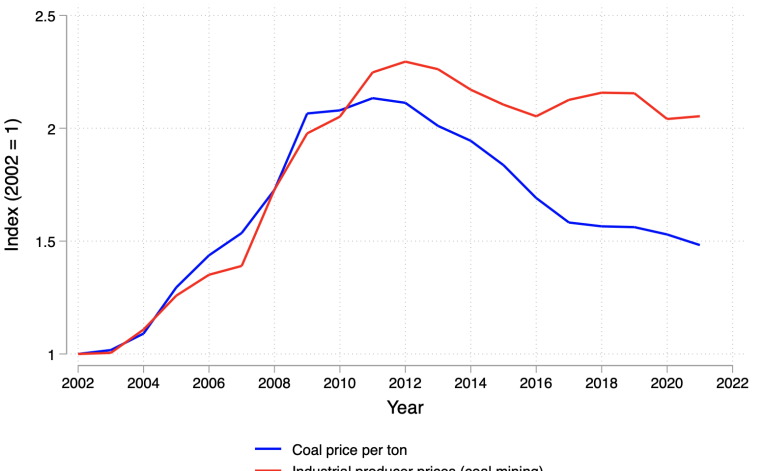
Where we are

Data

- **S&P Capital IQ**: coal mine-level power plant contracts and coal seam height data
- **FRED**: Monthly Producer Price Index for coal mining
- **BEA**: State-level real GDP data

	mean	sd	min	max	count
Ln Coal contract quantity (tons)	2.8096	1.377317	-6.907755	8.282483	135315
Ln Real contract coal price per ton	3.55144	.3352458	-1.94591	6.861505	135315
Time trend	6.743687	4.946114	0	19	135315
Ln GDP	12.54432	.7256892	10.83782	14.87147	135315
Coal seam height (in.)	82.63363	22.40209	0	168	32290
Observations	135315				

Figure


2.5
2
1.5
1
Index (2002 = 1)
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Year
Coal price per ton
Industrial producer prices (coal mining)

Empirical strategy - linear time trend, OLS

Full OLS specification with selection on observables:

$$\log(Quantity_{it}) = \beta_1 \log(Price_{it}) + \gamma_t \left(t \times \log(Price_{it})\right) + \tilde{\gamma}_t t + \theta_i + X_{it}'\beta_2 + \epsilon_{it}$$

- time period $t \in \{0, ..., T\}$, contract i
- $Quantity_{it}$: quantity in tons of coal in contract
- $Price_{it}$: price per ton of coal in contract
- θ_i: contracting power plant fixed effect
- X_{it}: covariates (GDP, etc.)

Empirical results - linear time trend, OLS

	(1)	(2)	(3)	(4)
Ln Real coal price per ton	-0.281**	-0.190**	-0.306	-0.280**
	(0.1254)	(0.0933)	(0.3027)	(0.1308)
Ln GDP	-0.0148	0.765*	-1.312	-0.0145
	(0.4494)	(0.4610)	(1.1596)	(0.4443)
Time trend	0.00115	-0.0329***	0.0199	0.00182
	(0.0090)	(0.0109)	(0.0205)	(0.0690)
Ln Real coal price per ton × Time trend				-0.000196
				(0.0195)
Constant	4.814	-5.401	21.36	4.805
	(5.6320)	(5.7299)	(14.9995)	(5.4895)
Power plant fixed effects	Yes	Yes	Yes	Yes
Observations	135315	92481	42834	135315
R^2	0.338	0.359	0.360	0.338
Adjusted R^2	0.336	0.357	0.357	0.336

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Empirical strategy - linear time trend, IV

Structural equation:

$$\log(Quantity_{it}) = \beta_1 \log(Price_{it}) + \gamma_t \left(t \times \log(Price_{it})\right) + \tilde{\gamma}_t t + X_{it}'\beta_2 + \epsilon_{it}$$

Reduced form equations for the first-stage:

$$\log(Price_{it}) = \pi_{01} SeamHeight_{it} + \alpha_{0t} \left(t \times SeamHeight_{it}\right) + \tilde{\alpha}_{0t} t + X_{it}'\pi_{02} + \nu_{0it}$$

$$t \times log(Price_{it}) = \pi_{11} SeamHeight_{it} + \alpha_{1t} \left(t \times SeamHeight_{it}\right) + \tilde{\alpha}_{1t} t + X_{it}'\pi_{12} + \nu_{1it}$$

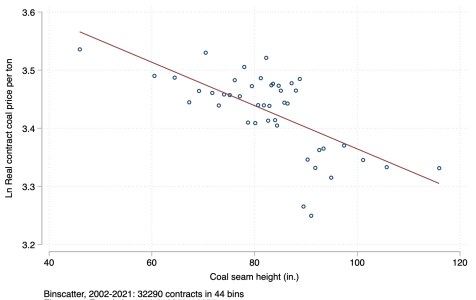
- time period $t \in \{0, ..., T\}$, contract i
- $Quantity_{it}$: quantity in tons of coal in contract
- $Price_{it}$: price per ton of coal in contract
- $SeamHeight_{it}$: contracting mine coal seam height in inches
- X_{it}: covariates (GDP, etc.)

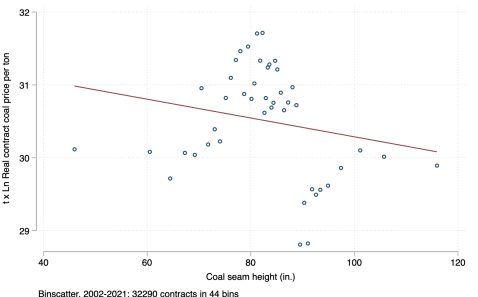
Empirical results - linear time trend, IV

```
. ivregress 2sls lncoalqty lnrealgdp t (lnrealcoalprice c.lnrealcoalprice#c.t = seam_height_in c.seam_height_
> in#c.t), robust first

First-stage regressions
-----------------------

                                                Number of obs =  32,290
                                                F(4, 32285)   = 1440.61
                                                Prob > F      =  0.0000
                                                R-squared     =  0.1384
                                                Adj R-squared =  0.1382
                                                Root MSE      =  0.2974

------------------------------------------------------------------------------
                     |               Robust
     lnrealcoalprice | Coefficient  std. err.      t    P>|t|     [95% conf. interval]
---------------------+--------------------------------------------------------
           lnrealgdp |   .0925013    .002295    40.31   0.000     .0880031    .0969996
                   t |  -.0402758   .0012027   -33.49   0.000    -.0426331   -.0379185
      seam_height_in |  -.0037298   .0001564   -23.85   0.000    -.0040363   -.0034233
                     |
c.seam_height_in#c.t |   .0003089   .0000145    21.29   0.000     .0002804    .0003373
                     |
               _cons |   2.717818   .0314011    86.55   0.000      2.65627    2.779365
------------------------------------------------------------------------------

                                                Number of obs =    32,290
                                                F(4, 32285)   = 291754.12
                                                Prob > F      =    0.0000
                                                R-squared     =    0.9750
                                                Adj R-squared =    0.9750
                                                Root MSE      =    2.8592

------------------------------------------------------------------------------
c.                   |               Robust
 lnrealcoalprice#c.t | Coefficient  std. err.      t    P>|t|     [95% conf. interval]
---------------------+--------------------------------------------------------
           lnrealgdp |   .8116657   .0225328    36.02   0.000     .7675005    .8558309
                   t |   3.107188    .013436   231.26   0.000     3.080853    3.133523
      seam_height_in |  -.0129057   .0010074   -12.81   0.000    -.0148801   -.0109312
                     |
c.seam_height_in#c.t |   .0015935   .0001582    10.08   0.000     .0012835    .0019035
                     |
               _cons |  -7.776669   .3007634   -25.86   0.000    -8.366176   -7.187161
------------------------------------------------------------------------------
```

Empirical results - linear time trend, IV

Relevance:





Exogeneity: variation in coal seam can be treated as an exogeneous supply shock

Empirical results - linear time trend, IV

```
Instrumental variables 2SLS regression          Number of obs   =     32,290
                                                Wald chi2(4)    =     586.67
                                                Prob > chi2     =     0.0000
                                                R-squared       =          .
                                                Root MSE        =     1.7253

------------------------------------------------------------------------------
             |               Robust
    lncoalqty |  Coefficient  std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
lnrealcoalprice |  -6.541249   .3664515   -17.85   0.000    -7.259481   -5.823017
             |
c.lnrealcoalprice#c.t |   .7910052   .0965278     8.19   0.000     .6018143    .9801962
             |
     lnrealgdp |  -.0350992   .0628476    -0.56   0.577    -.1582781    .0880797
             t |  -2.628501   .3165763    -8.30   0.000    -3.248979   -2.008023
         _cons |   25.68733    1.61848    15.87   0.000     22.51517    28.85949
------------------------------------------------------------------------------
Instrumented: lnrealcoalprice c.lnrealcoalprice#c.t
 Instruments: lnrealgdp t seam_height_in c.seam_height_in#c.t
```

Empirical strategy - time dummies, OLS

Full OLS specification with selection on observables:

$$\log(Quantity_{it}) = \beta_1 \log(Price_{it}) + \sum_{t=0}^{T} \gamma_t \left(\tau_t \times \log(Price_{it})\right) + \sum_{t=0}^{T} \tilde{\gamma}_t \tau_t + \theta_i + X_{it}' \beta_2 + \epsilon_{it}$$

- time period t, contract i
- $Quantity_{it}$: quantity in tons of coal in contract
- $Price_{it}$: price per ton of coal in contract
- τ_t: time period dummy
- θ_i: contracting power plant fixed effect
- X_{it}: covariates (GDP, etc.)

Empirical strategy - time dummies, IV

Structural equation:

$$\log(Quantity_{it}) = \beta_1 \log(Price_{it}) + \sum_{t=0}^{T} \gamma_t \left(\tau_t \times \log(Price_{it})\right) + \sum_{t=0}^{T} \tilde{\gamma}_t \tau_t + X_{it}'\beta_2 + \epsilon_{it}$$

$T+1$ **reduced form equations for the first-stage**:

$$\log(Price_{it}) = \pi_{01} SeamHeight_{it} + \sum_{t=0}^{T} \alpha_{0t} \left(\tau_t \times SeamHeight_{it}\right) + \sum_{t=0}^{T} \tilde{\alpha}_{0t} \tau_t + X_{it}'\pi_{02} + \nu_{0it}$$

$$\tau_1 \times log(Price_{i1}) = \pi_{11} SeamHeight_{it} + \sum_{t=0}^{T} \alpha_{1t} \left(\tau_t \times SeamHeight_{it}\right) + \sum_{t=0}^{T} \tilde{\alpha}_{1t} \tau_t + X_{it}'\pi_{12} + \nu_{1it}$$

$$\vdots$$

$$\tau_T \times log(Price_{iT}) = \pi_{T1} SeamHeight_{it} + \sum_{t=0}^{T} \alpha_{Tt} \left(\tau_t \times SeamHeight_{it}\right) + \sum_{t=0}^{T} \tilde{\alpha}_{Tt} \tau_t + X_{it}'\pi_{T2} + \nu_{Tit}$$

- time period t, contract i
- $Quantity_{it}$: quantity in tons of coal in contract
- $Price_{it}$: price per ton of coal in contract
- $SeamHeight_{it}$: contracting mine coal seam height in inches
- τ_t: time period dummy
- X_{it}: covariates (GDP, etc.)

Replication vs. extension

[Figure: Normalize all estimates to 0 in 2000 and plot evolution of elasticities for replication, OLS extension, and IV extension]

Conclusions

- Burke and Liao (2015) results are not externally valid